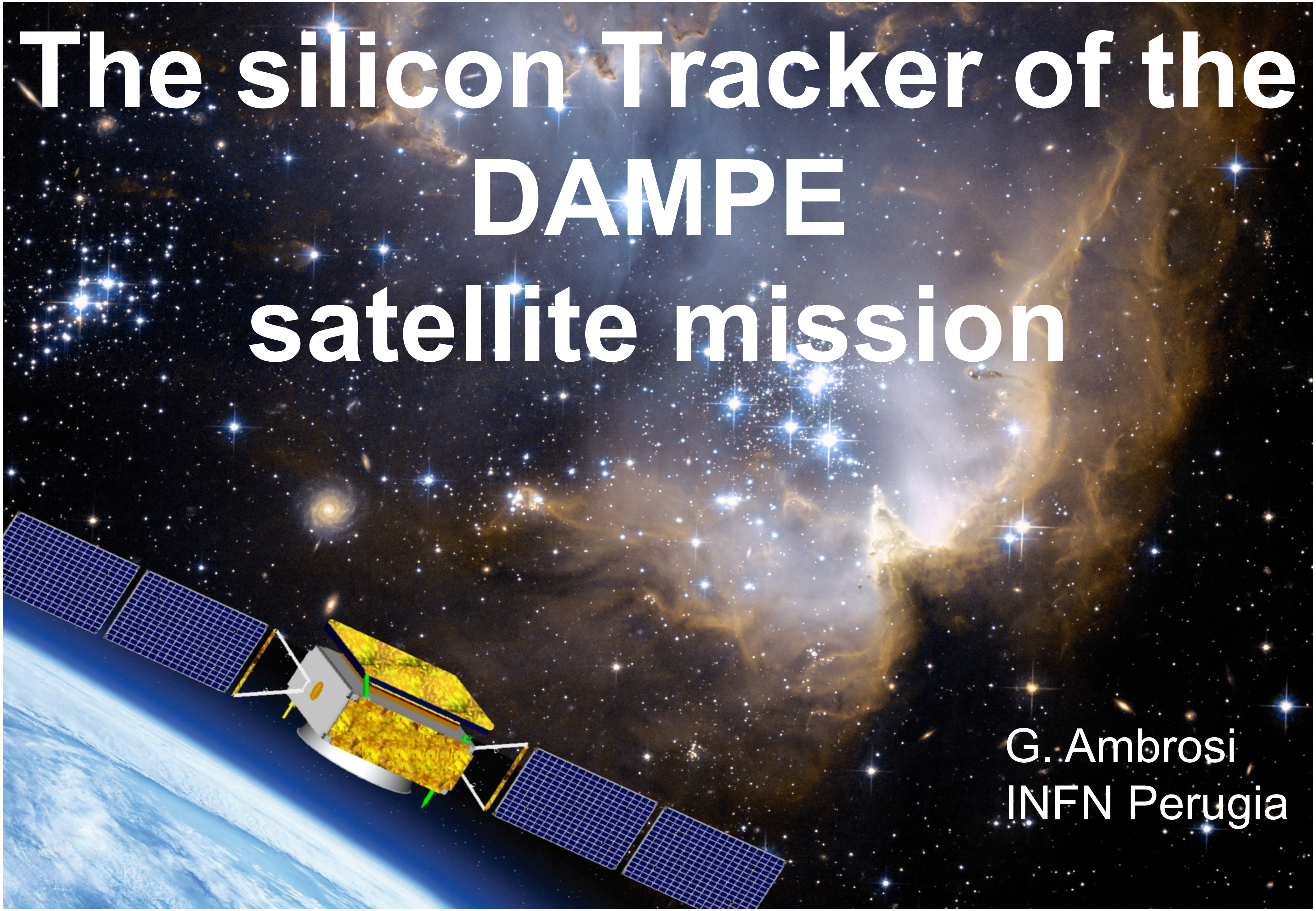
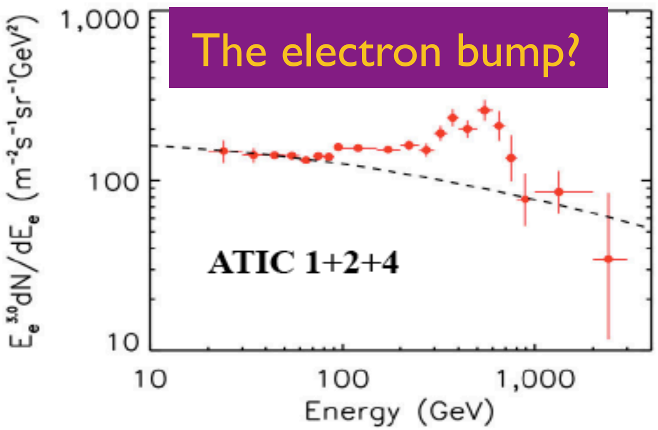
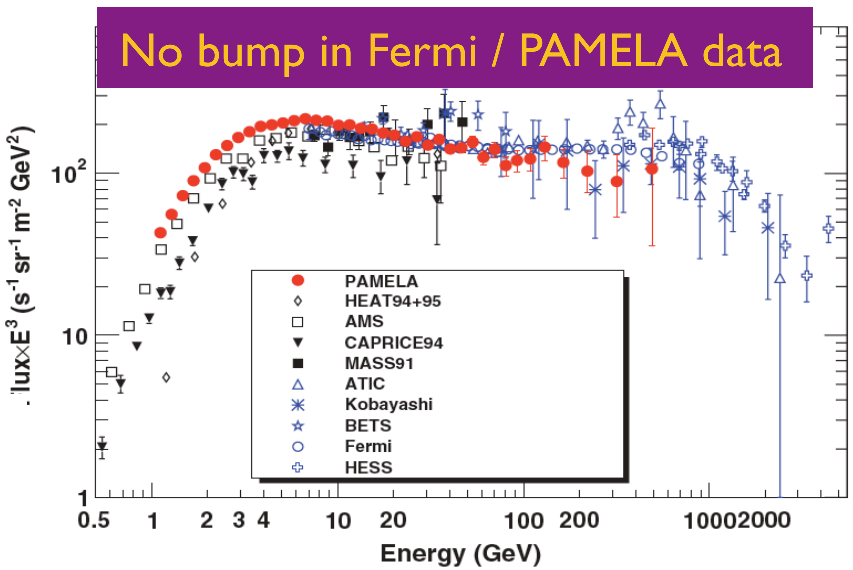
The silicon Tracker of the DAMPE satellite mission

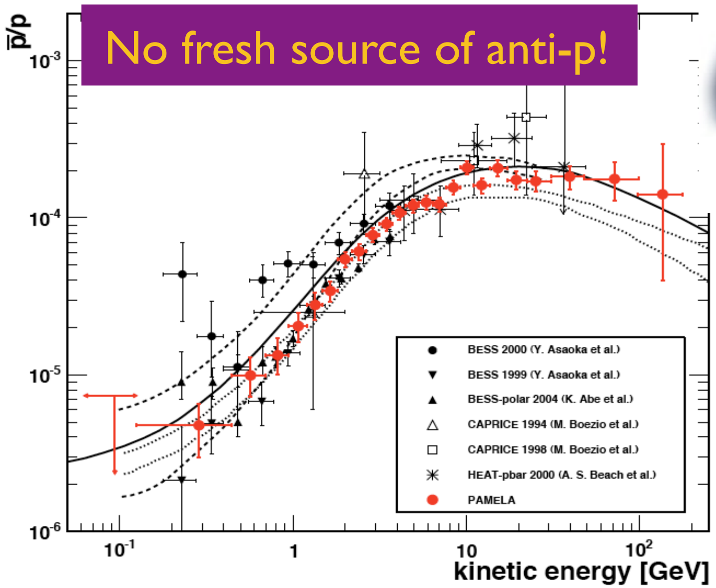


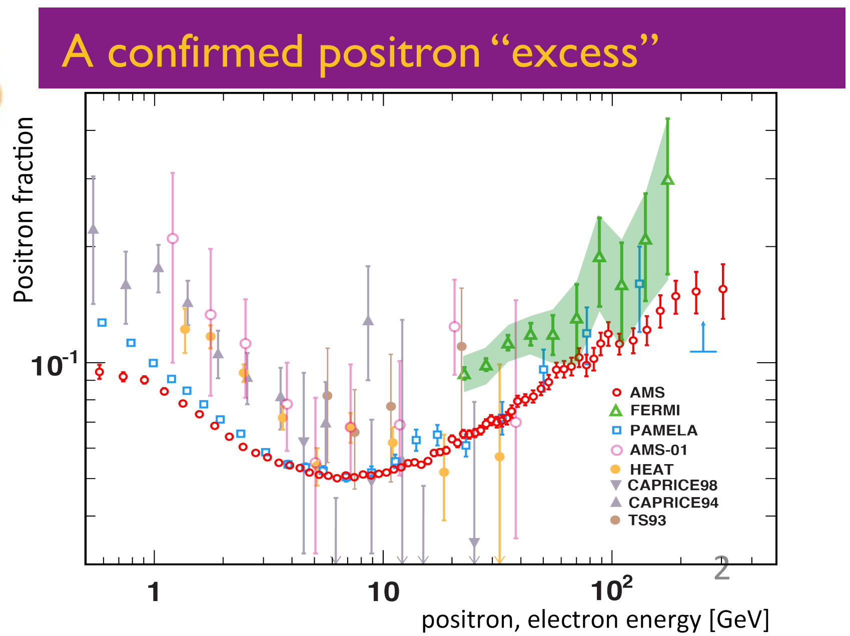
G. Ambrosi
INFN Perugia

Anti-matter & Exotic sources (DM ?)









Scientific Objectives of DAMPE

- High energy particle detection in space
  - Search for Dark Matter signatures
  - Study of cosmic ray spectrum and composition
  - High energy gamma astronomy
- Follow-up mission to Pamela, Fermi/LAT and AMS-02
  - Extend the energy reach and better resolution
  - Run in parallel for some time
- Followed by HERD on the Chinese space station

NEWS & ANALYSIS

Science, 20 May 2011

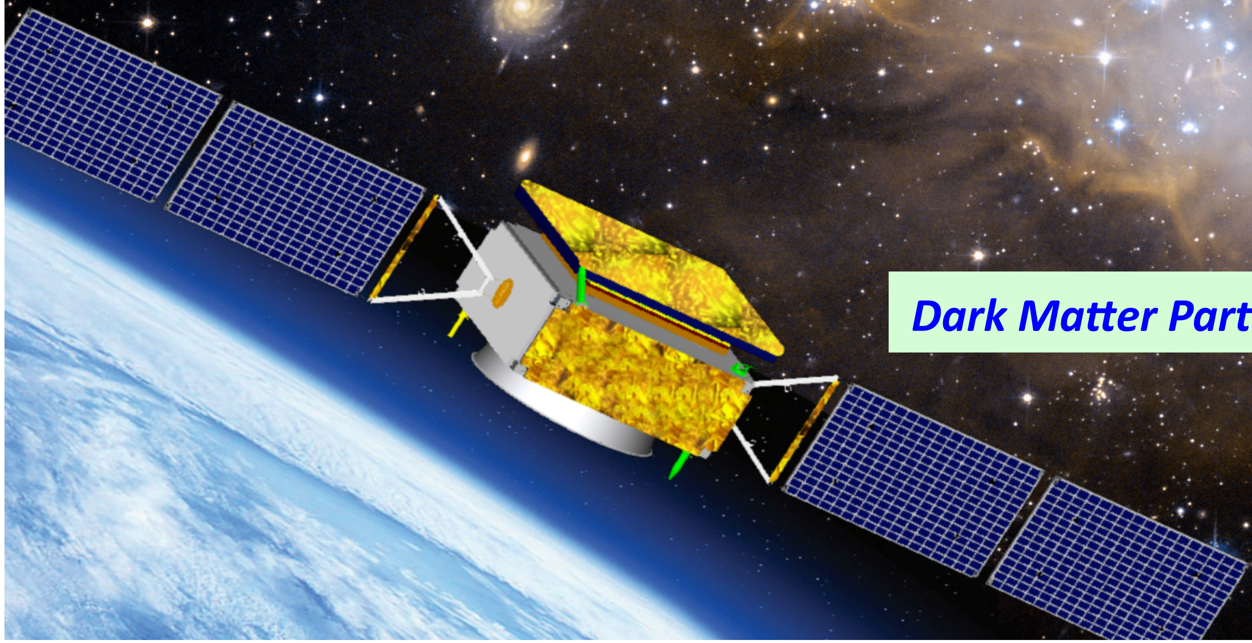
SPACE SCIENCE

Chinese Academy Takes Space Under Its Wing

LOFTY AMBITIONS

Mission	Chief scientist	Goals	Estimated launch
HXMT	Li Tipei, CAS Institute of High Energy Physics and Tsinghua University	Survey of x-ray sources; detailed observations of known objects	2014
Shijian-10	Hu Wenrui, CAS Institute of Mechanics	Study physical and biological systems in microgravity and strong radiation environment	Early 2015
KuaFu Project	William Liu, Canadian Space Agency and CAS Center for Space Science and Applied Research	Study solar influence on space weather	Mid-2015
Dark Matter Satellite	Chang Jin, CAS Purple Mountain Observatory	Search for dark matter; study cosmic ray acceleration	Late 2015
Quantum Science Satellite	Pan Jianwei, University of Science and Technology of China	Quantum key distribution for secure communication; long-distance quantum entanglement	2016

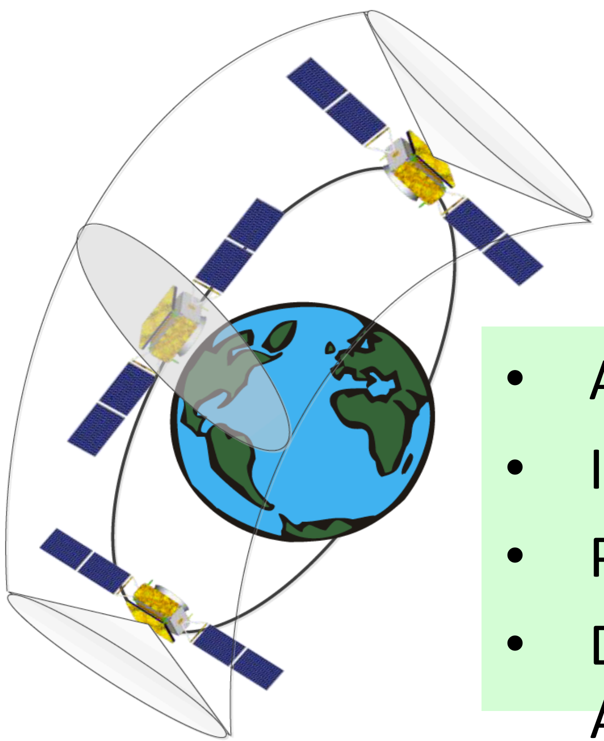
Strategic Priority Research Program in Space Science



Dark Matter Particle Explorer Satellite

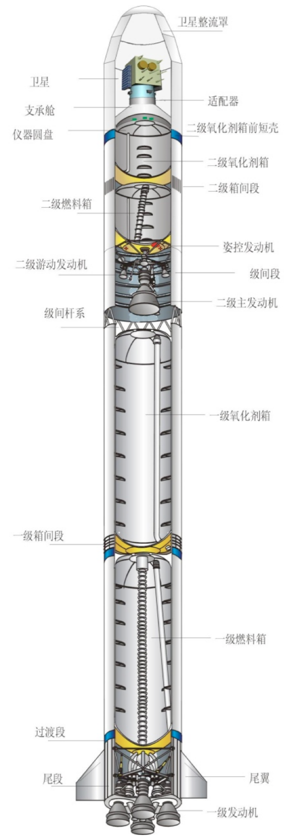
Dark Matter Particle Explorer Satellite

- One of the 5 satellite missions of the Strategic Priority Research Program in Space Science of CAS
  - Approved for construction (phase C/D) in Dec. 2011
  - Scheduled launch date 2015-2016

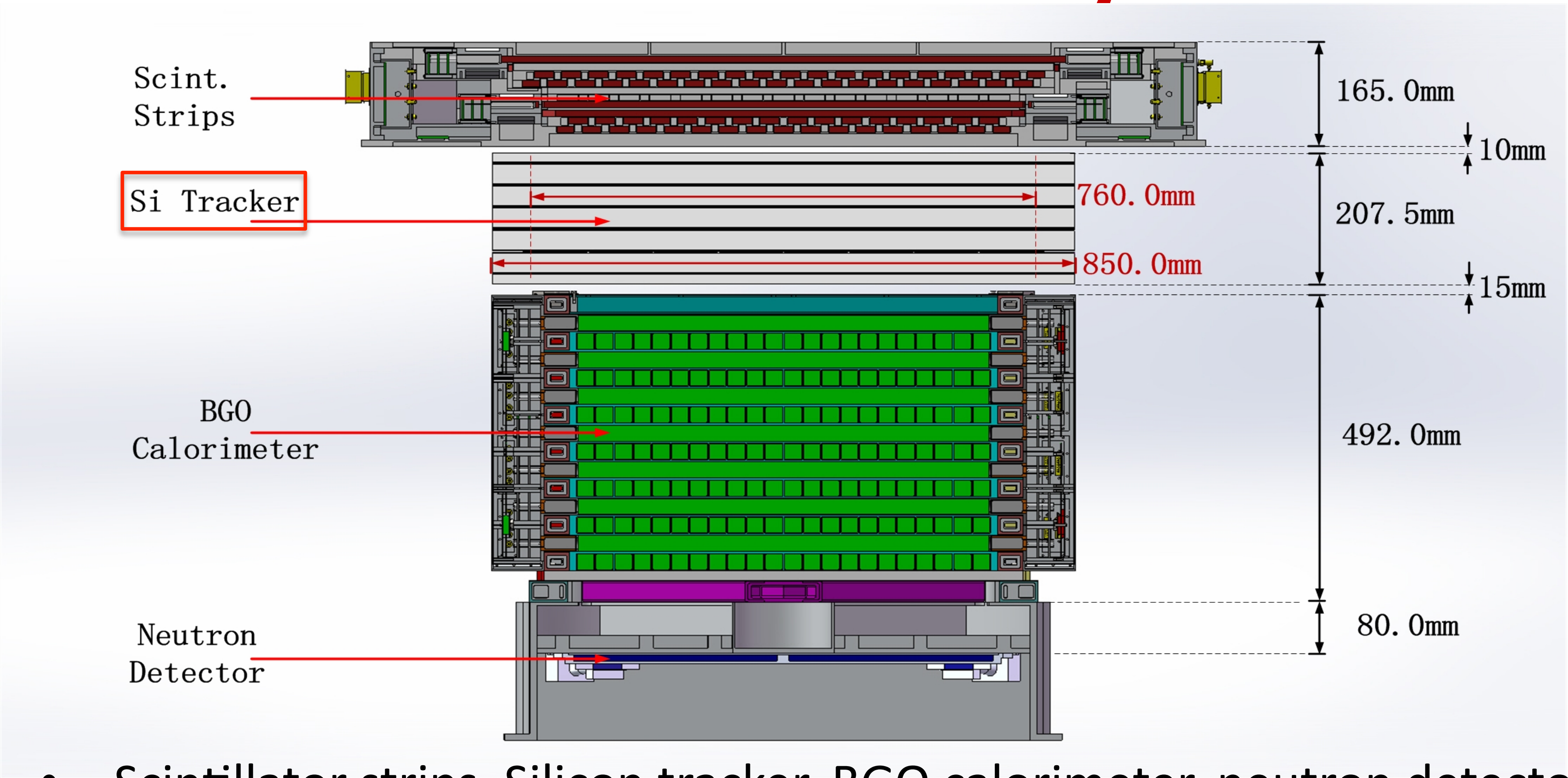


- Satellite < 1900 kg, payload ~1340kg
- Power consumption 840W
- Lifetime > 3 years
- Launched by CZ-2D rockets

- Altitude 500 km
- Inclination 87.4065°
- Period 90 minutes
- Dawn/dusk (6:30 AM) sun-synchronous orbit

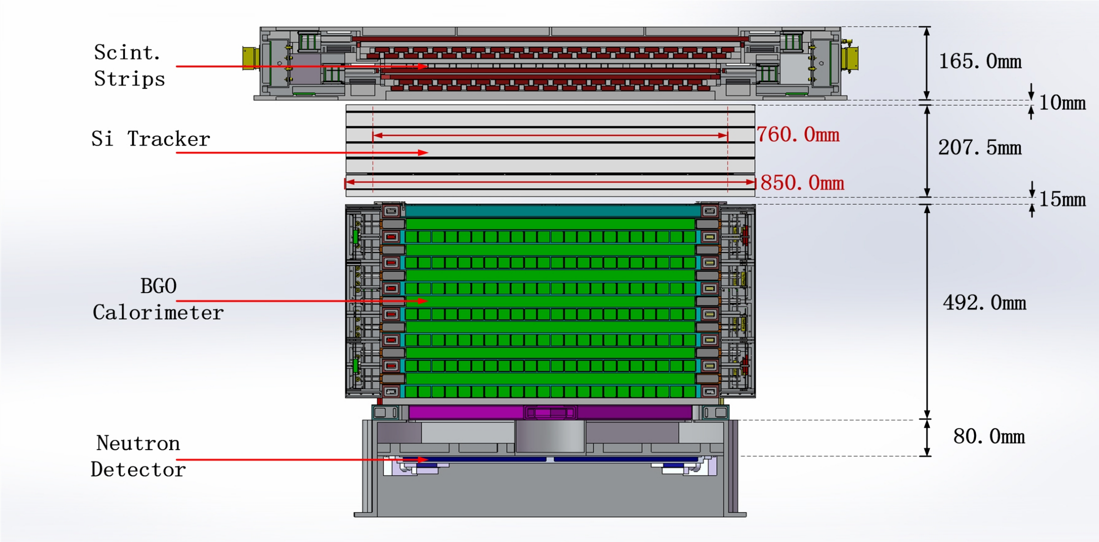


DAMPE Detector Layout



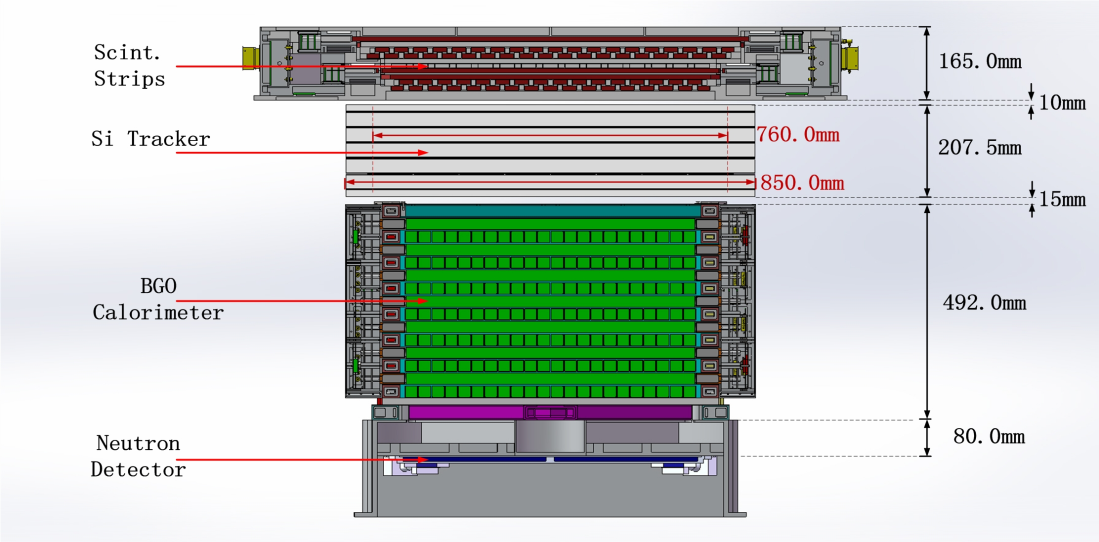
- Scintillator strips, Silicon tracker, BGO calorimeter, neutron detector
- Combine a γ-ray space telescope with a deep imaging calorimeter
  - Total ~33 X_0 → deepest detector in space
  - **Silicon tracker approved in autumn 2012**

DAMPE detector layout



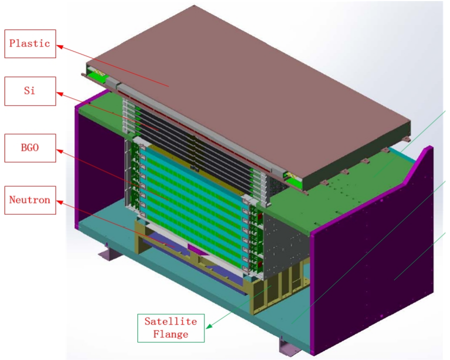
- Silicon tracker
  - 6 tracking layers, 12 silicon layers
  - 3 tungsten layers, 1.45 X_0
  - analog readout to measure position and charge (Z)
- BGO calorimeter:
  - 14 layers hodoscope, 31 X_0
  - 2.5x2.5x60 cm^3 BGO crystals
  - PMT with dynode readout
- Scintillator strips and neutron detector
  - scintillators + PMT

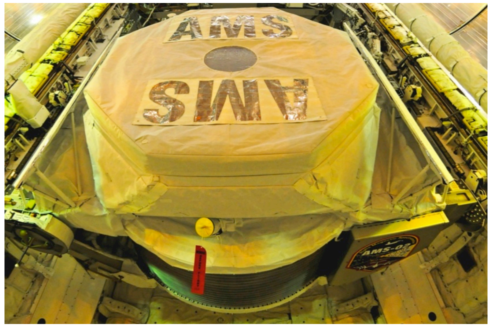
DAMPE Detector performance

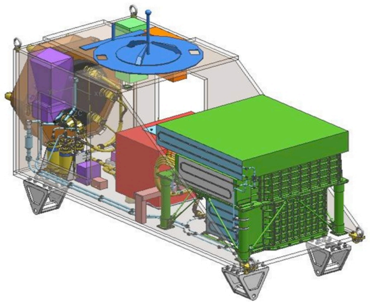


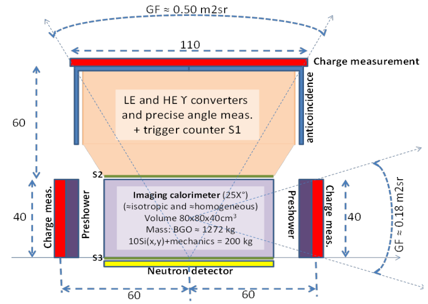
- energy range: 5 GeV – 10 TeV for electrons and photons
- energy range: O(100 GeV) – O(100 TeV) for protons and ions
- energy resolution: 1.5 % @ 800 GeV electrons
- energy resolution: 40 % @ 800 GeV protons
- e/p separation: 10^5
- geometrical acceptance: ~ 0.4 m^2sr
- angular resolution: 0.1°

DAMPE and other detectors



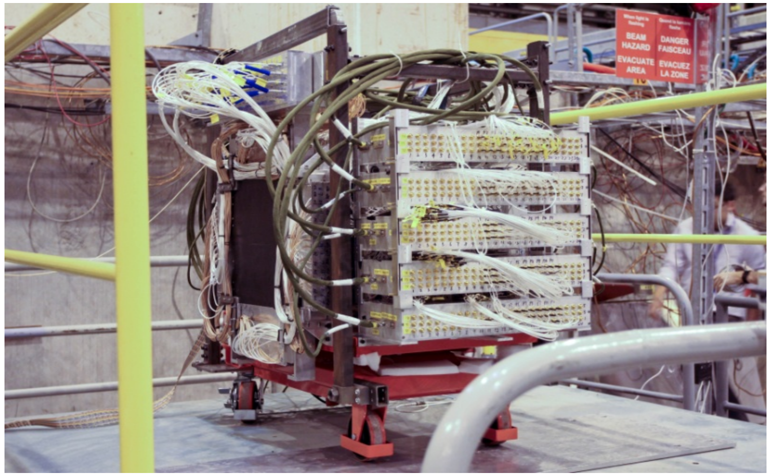


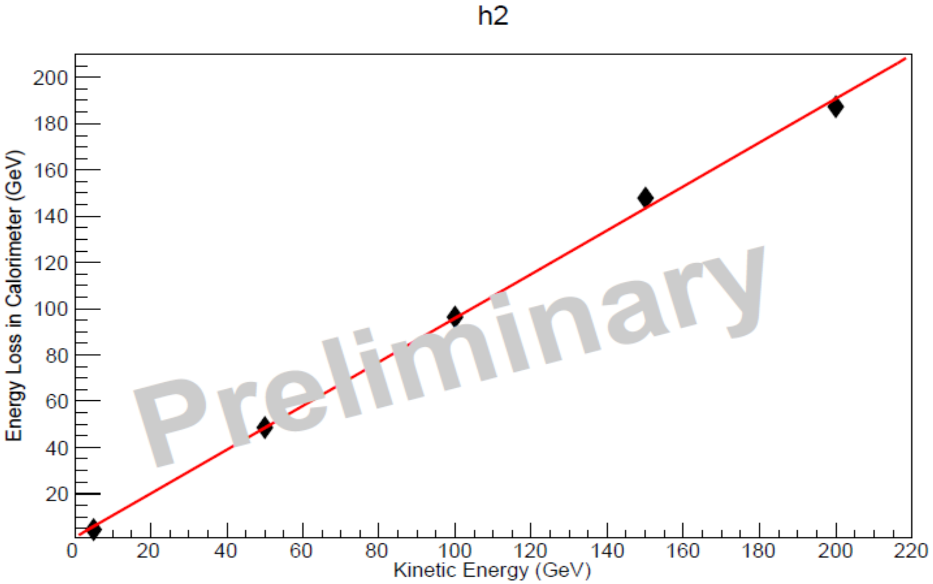


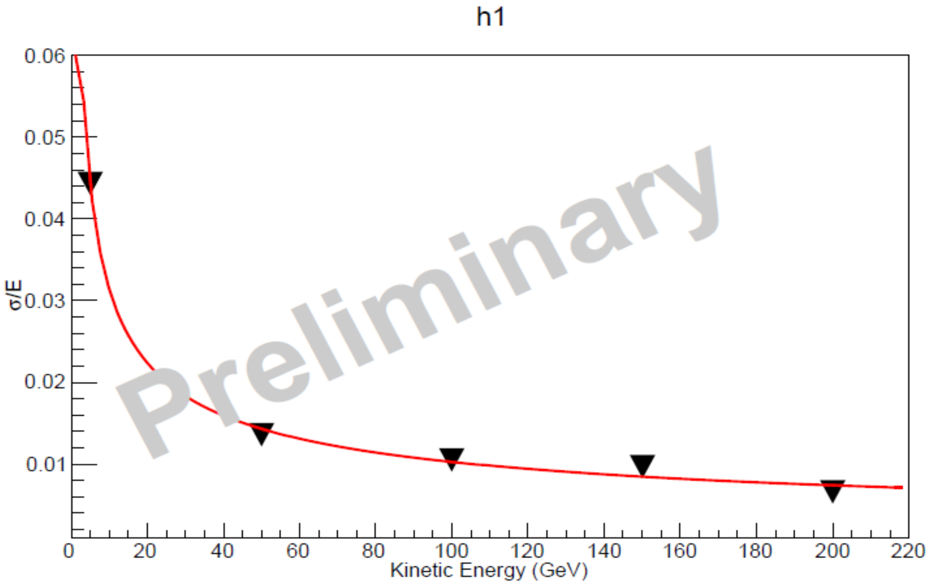


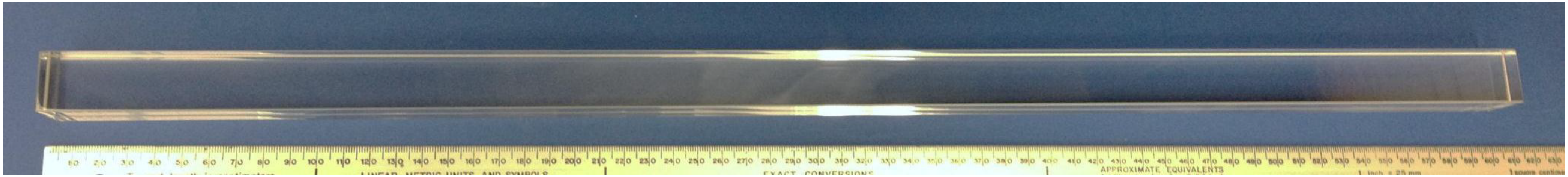
	DAMPE	AMS-02	Fermi LAT	CALET	GAMMA-400
Energy range (GeV)	5 - 10^4	0.1 - 10^3	0.02 - 300	1 – 2 10^4	0.1 – 3 10^3
e/γ Energy res.@100 GeV (%)	1.5	3	10	2	1
e/γ Angular res.@100 GeV (°)	0.1	0.3	0.1	0.1	0.01
e/p discrimination	10^5	10^5 - 10^6	10^3	10^5	10^6
Calorimeter thickness (X_0)	31	17	8.6	30	25
Geometrical accep. (m^2sr)	0.4	0.09	1	0.12	0.5

Calorimeter

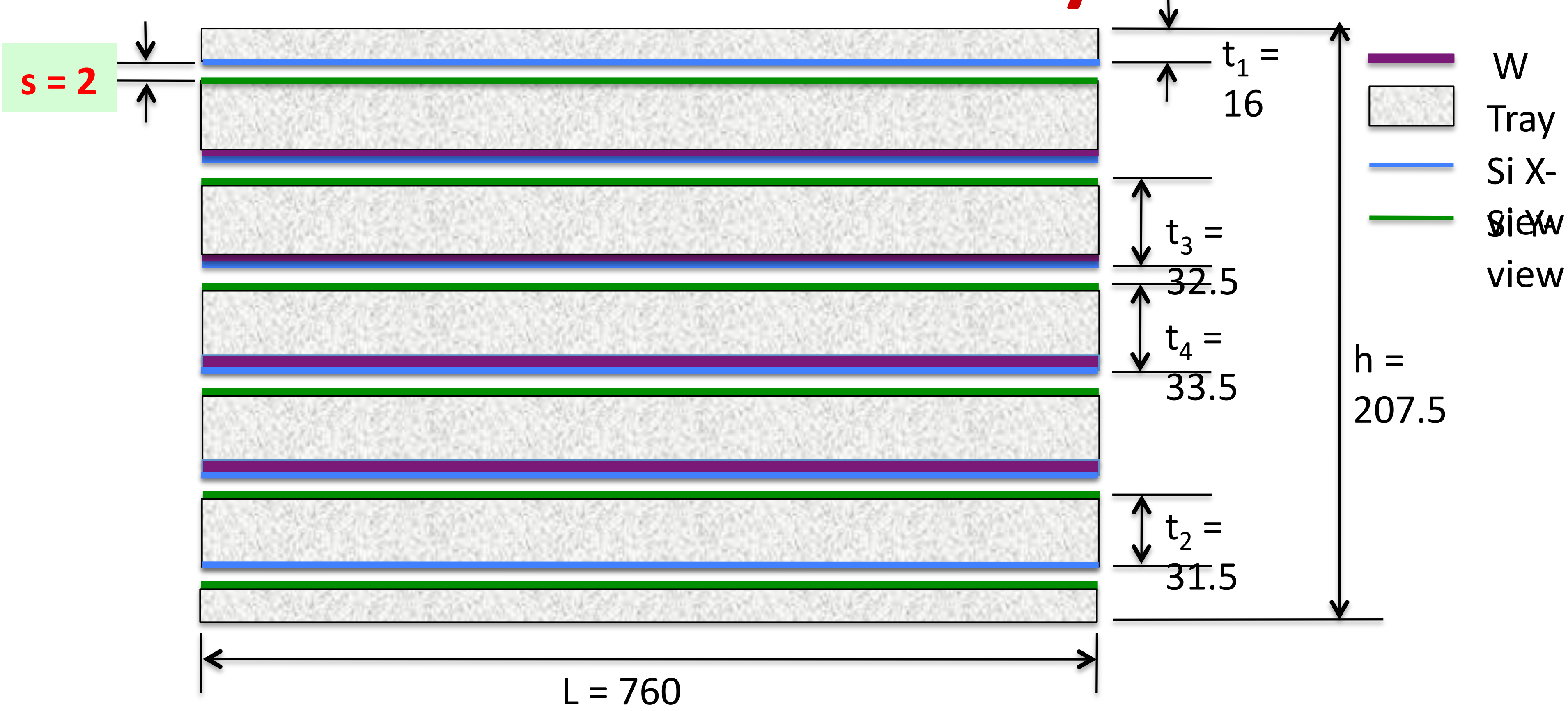






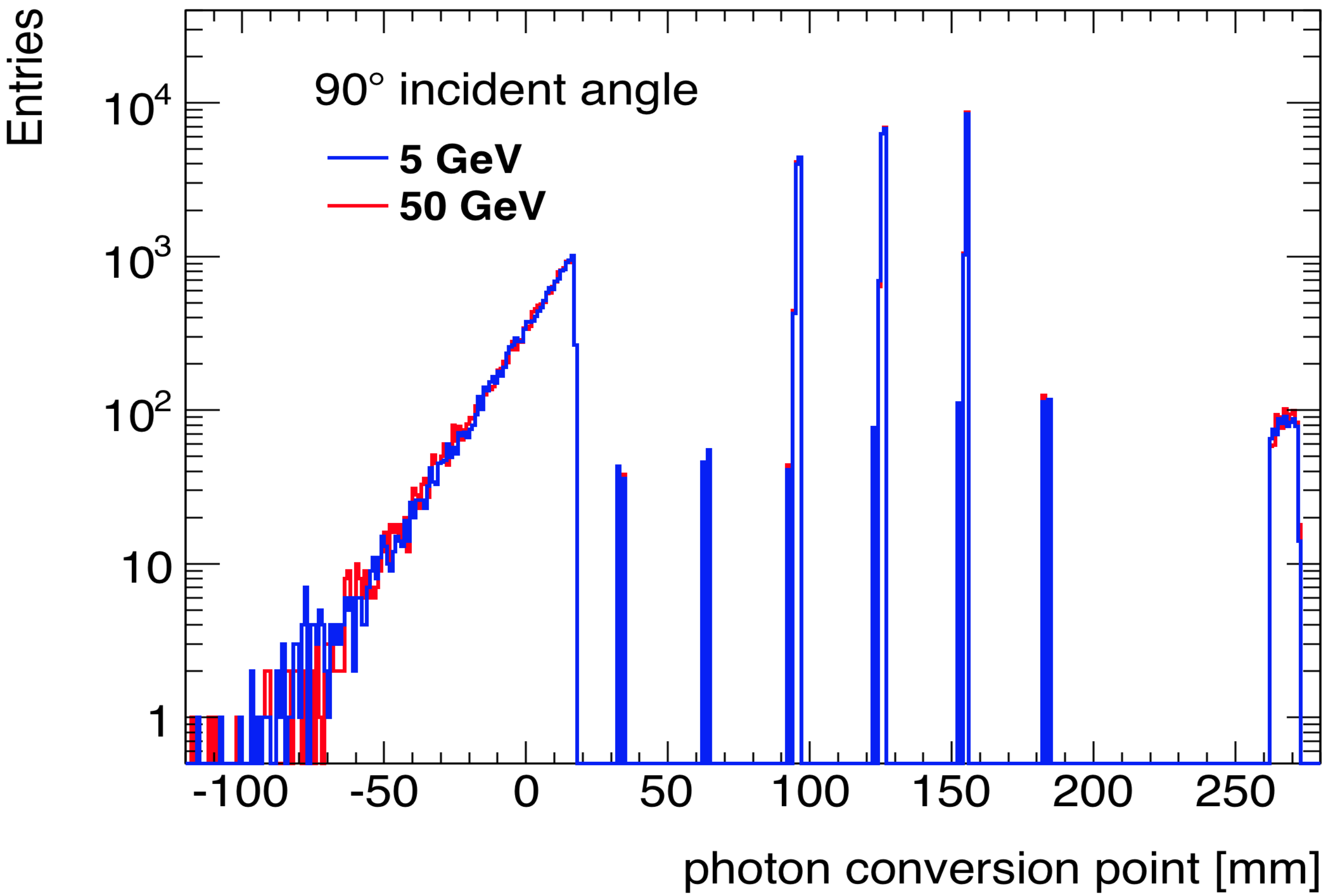


DAMPE Tracker Layout



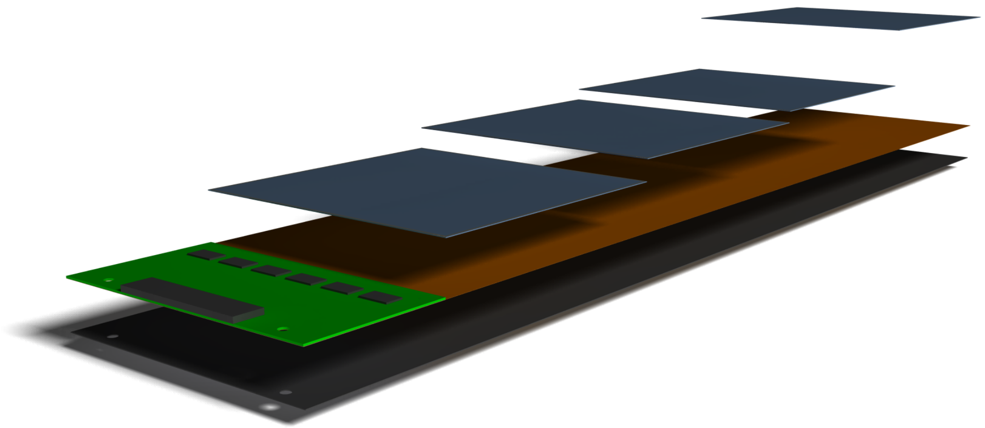
- 3 converter layers, total 67 kg of W, thickness 1 mm + 2x2 mm = 1.71 X_0
- A tracking plane is made of 2x8 ladders head to head
- 7 planes of 4 types: no-W thin tray, no-W thick tray, thin-W tray, thick-W tray
  - Support of thin tray ~ 15 mm, Support of thick tray ~ 30 mm

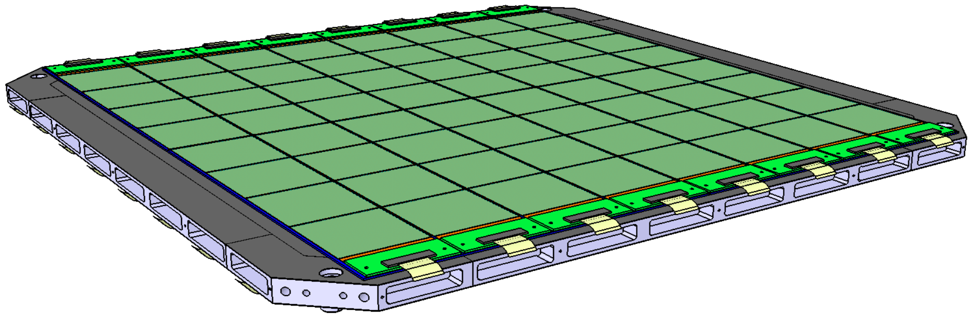
Gamma Conversion Probability

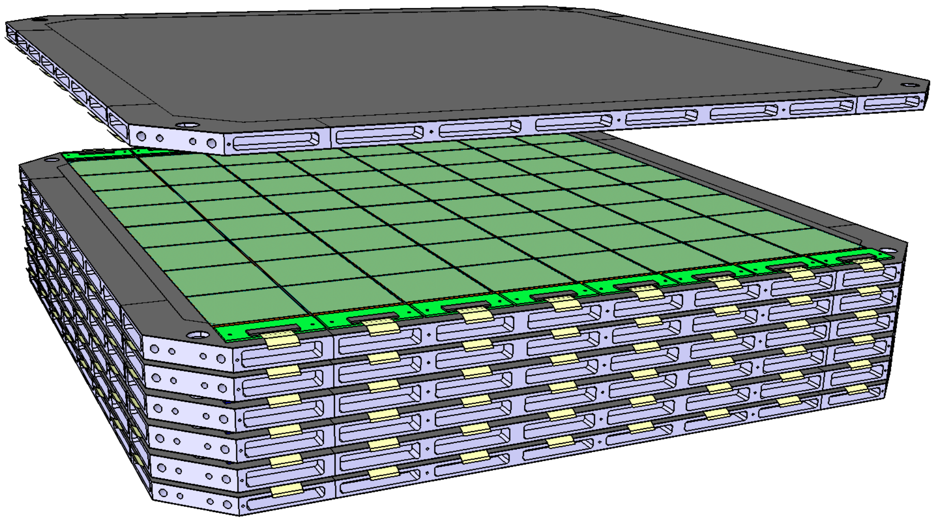


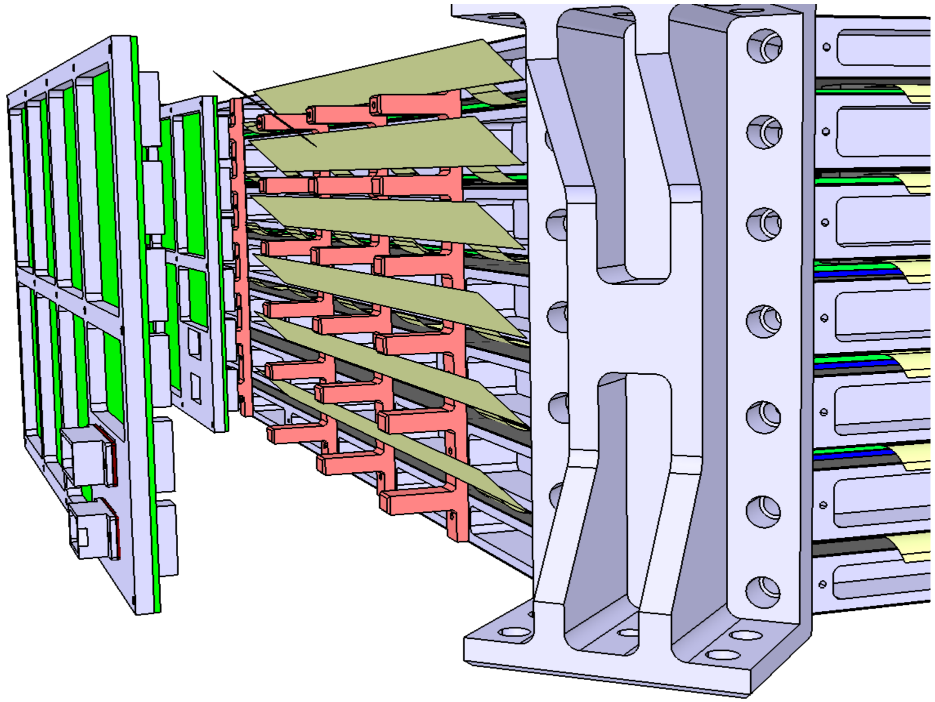
- Geant4 simulation using baseline layout
- ~65% conversion in W (32% in calorimeter)
  - 19% in 1mm W, 28% in first 2mm W, 18% in second 2mm W

Tracker structure

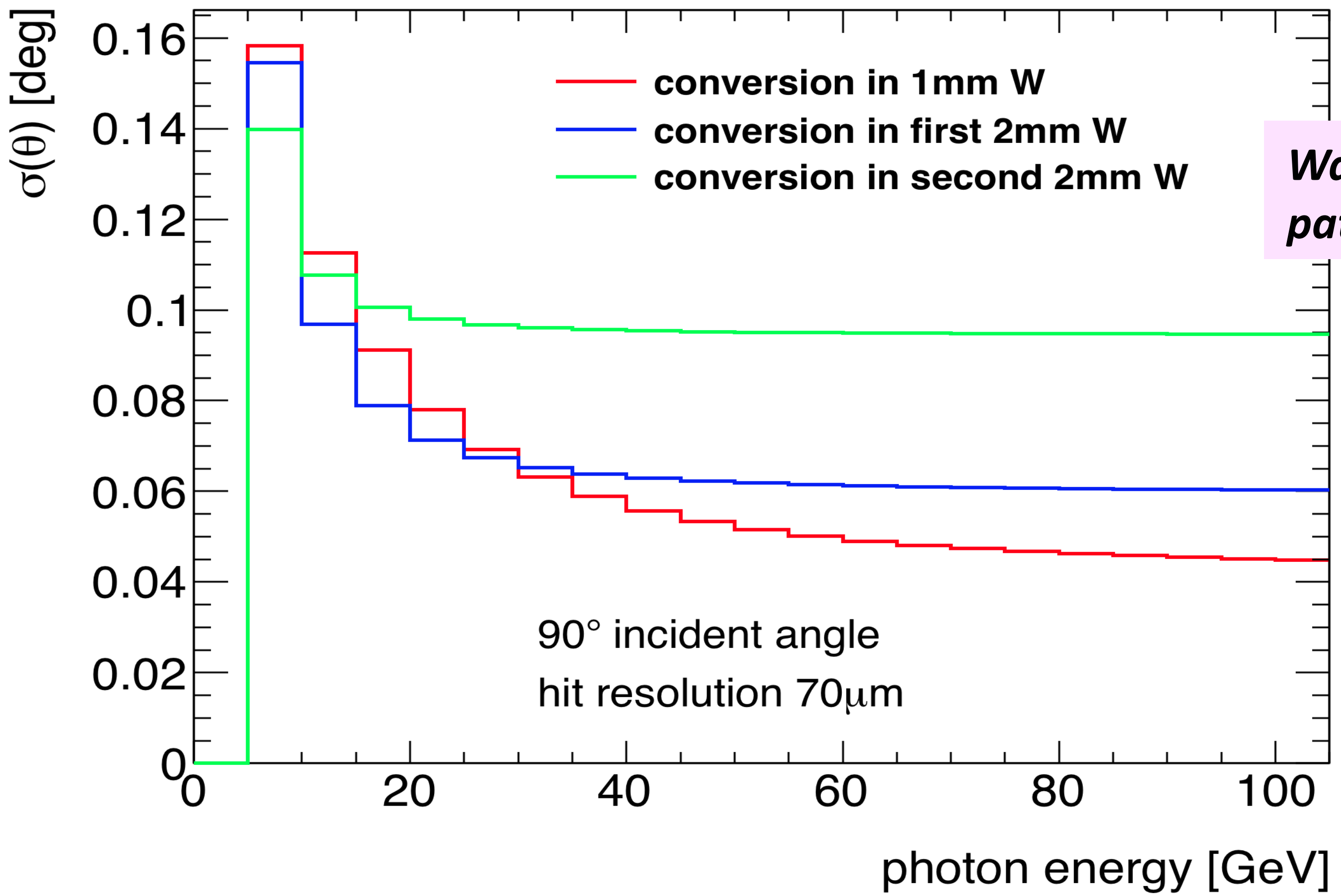








Angular resolution as function of energy



Warning: assume perfect pattern recognition!

- Estimated with Kalman filter using paper model with following assumptions
  - leading particle takes 77% of photon energy, average energy loss in W from Geant4, position resolution 70μm
- Asymptotic resolution depends on number of hits

DAMPE Tracker Components

- Silicon sensor (Hamamatsu)
  - use AGILE specification
- FE ASIC (Gamma Medica-Ideas)
  - use updated version of the AMS-02 ASICs, already available in INFN Perugia
- Electronics (IHEP, INFN Pg, DPNC)
  - use updated version of the AMS readout and power electronics
- Silicon ladder (INFN Pg +DPNC)
  - use of AMS-02 assembly methods
- Silicon plane and tracker assembly (DPNC + INFN Pg)

Proven technologies and profiting from previous experiences!

DAMPE Tracker timeline

- design and produce:
  - Engineering Qualification Model (EQM)
  - Flight Model (FM)
- EQM qualification is foreseen in spring 2014
- FM ladders production completed by the autumn 2014
- FM integration in winter 2014/2015
- FM qualification in spring 2015

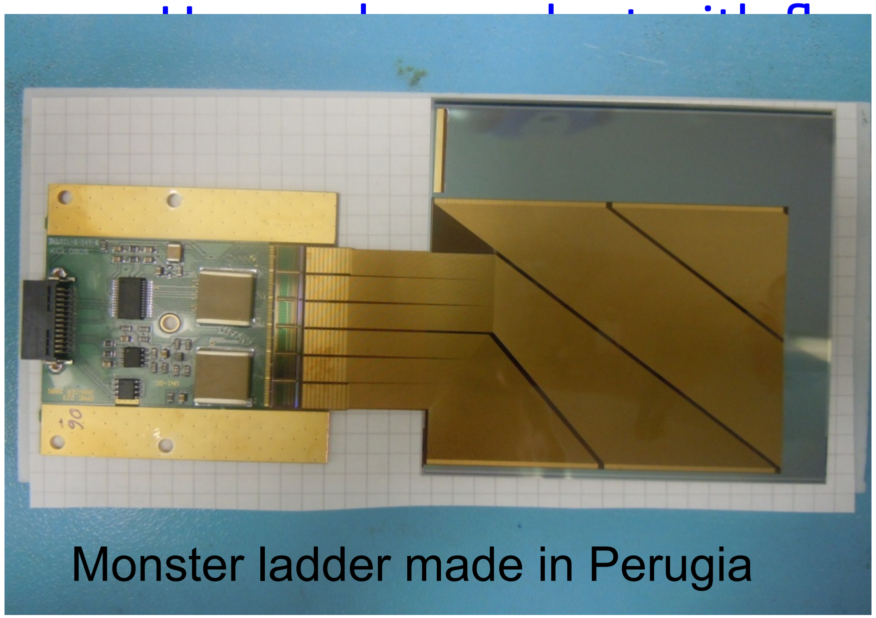
- we are currently in the material purchase/acquisition phase:

maintaining the schedule is the challenge

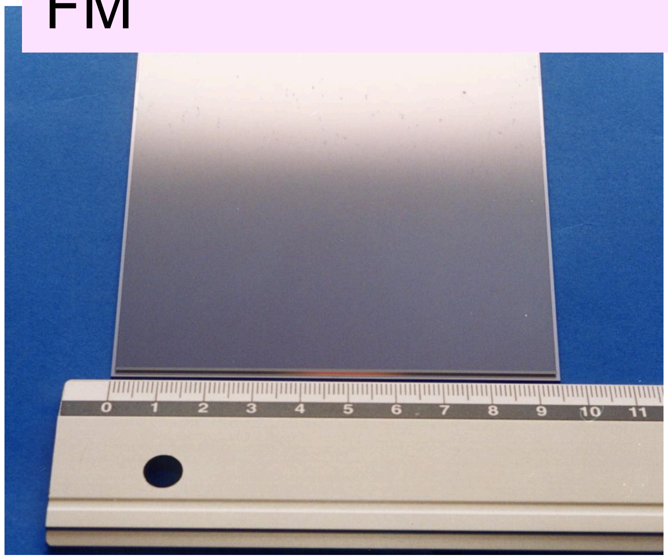
Silicon detectors

- Made by HAMAMATSU
- Single-side AC coupled, high resistivity (≥ 4 kΩ cm)
  - 9.5 x 9.5 cm^2 from 6 inch wafer, 320μm thick
- 768 physical strips with physical pitch 121 μm
  - Readout out half of the strips: 384 readout strips with pitch 242 μm
  - ting

~100 for EQM, 845 for FM



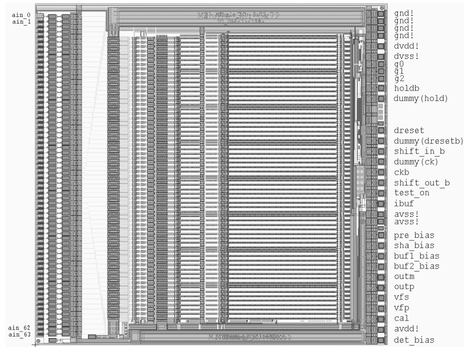
Monster ladder made in Perugia

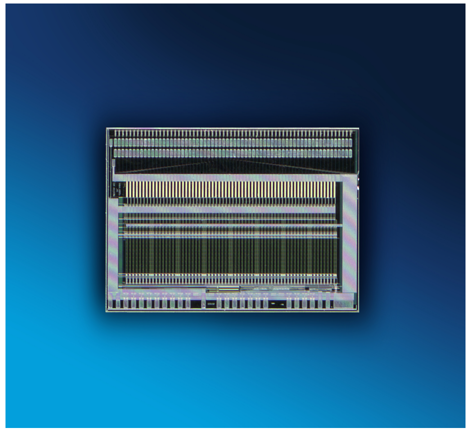


Readout ASICs

- Use updated version of the ASIC used by AMS-02: VA64HDR9a → VA140
  - By Gamma Medica-Ideas (Oslo), 0.35 µm (was 0.8) CMOS technology
  - Improved performance in noise, power and radiation tolerance
  - chips already available in Perugia

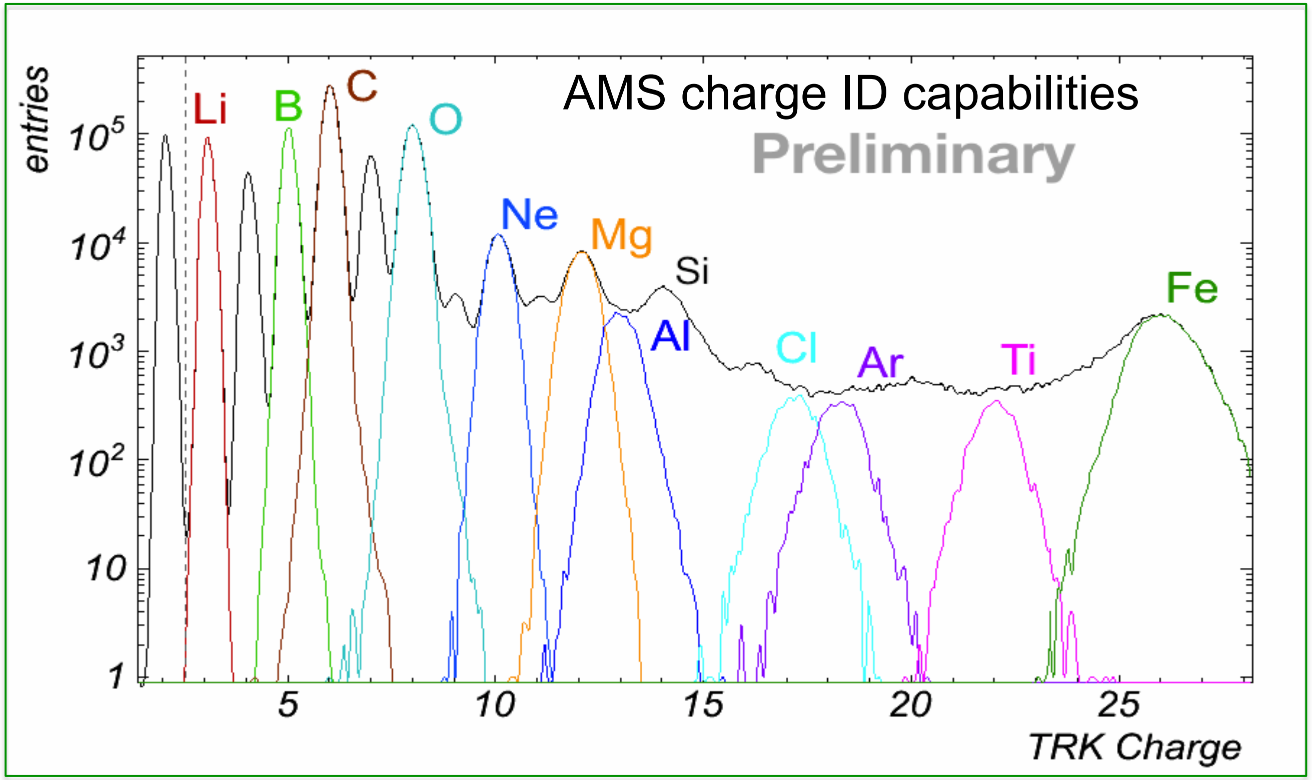
Parameter	VA64HDR9A	VA140
Noise, Cd=0pF (eRMS)	290	100
Noise, Cd=50pF (eRMS)	520	430
Noise, Cd=100pF (eRMS)	810	780
DNR	+100fC,-200fC	±200fC
Linearity ± 72fC		
Negative:	±6%	±2%
Positive:	±12%	±5.5%
Power cons. (mW/channel)	0.8	0.32
Peaking time (µs)	4.5	7.5

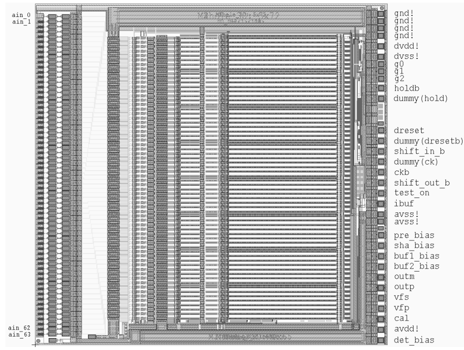


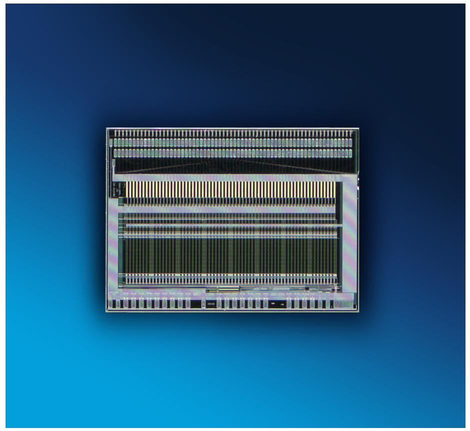


Readout ASICs

- Use updated version of the ASIC used by AMS-02: VA64HDR9a → VA140
  - By Gamma Medica-Ideas (Oslo), 0.35 µm (was 0.8) CMOS technology
  - Improved performance in noise, power and radiation tolerance
  - 10 chips already available in Perugia

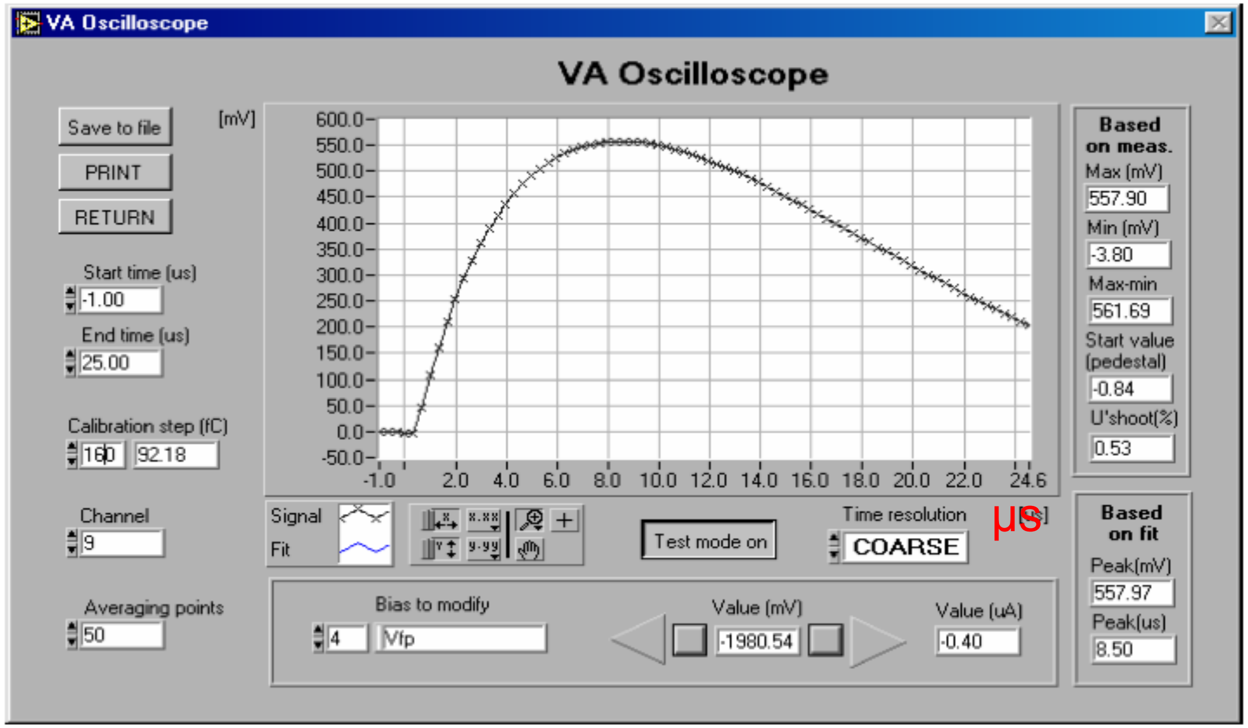


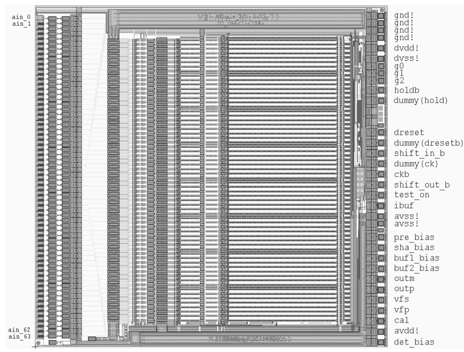


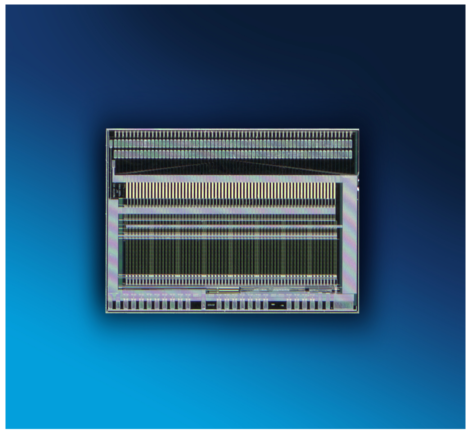


Readout ASICs, performance

- Shaping time ~ 8 us

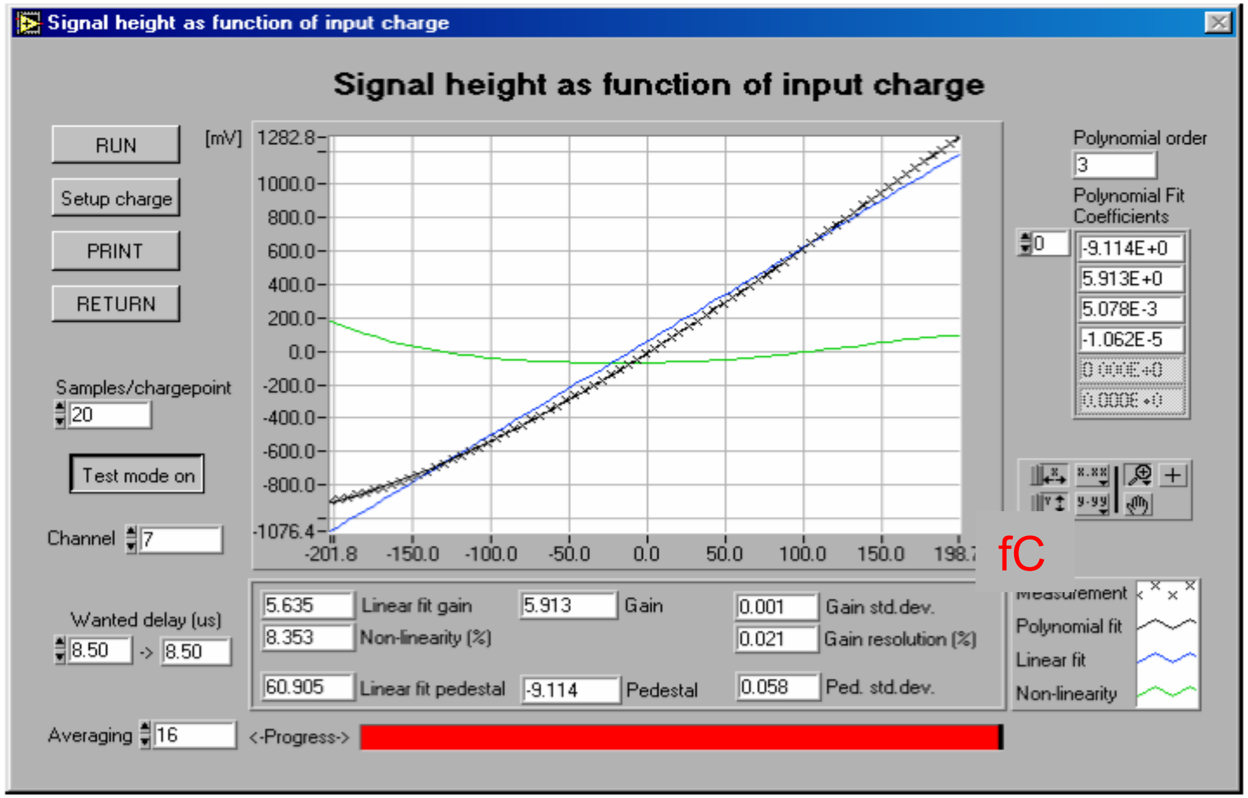


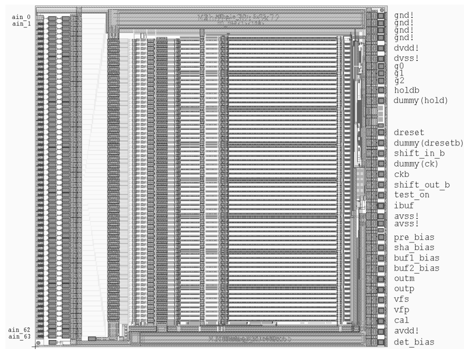


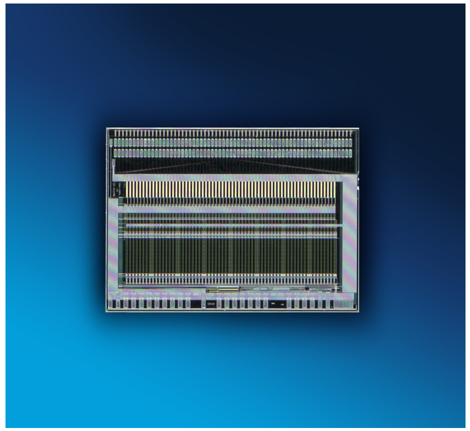


Readout ASICs, performance

- Dynamic range: linear up to 200 fC

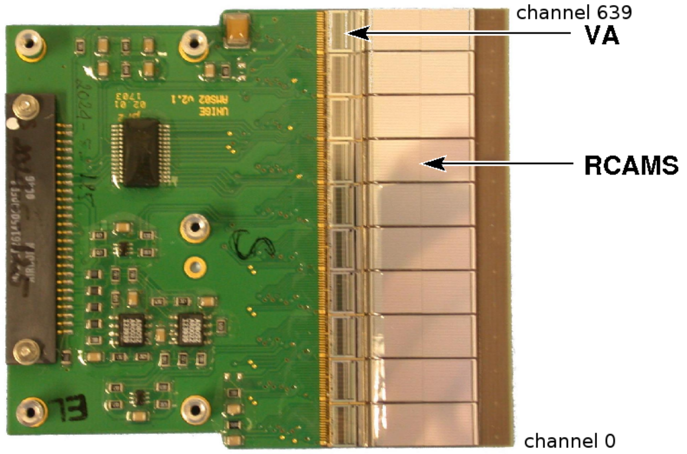


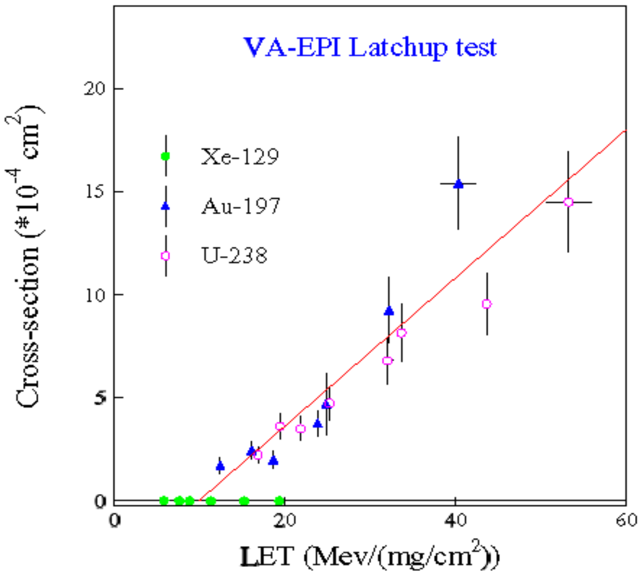


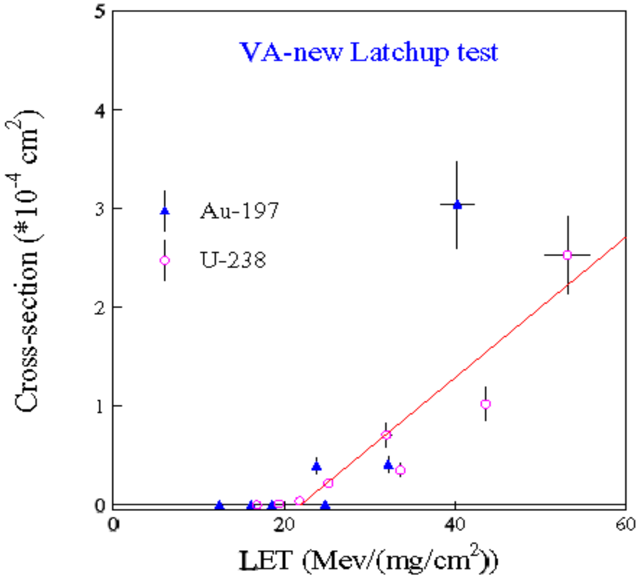


Radiation ‘hard’ electronics: the AMS-02 experience

The problem are the SEE (Single Event Effect)





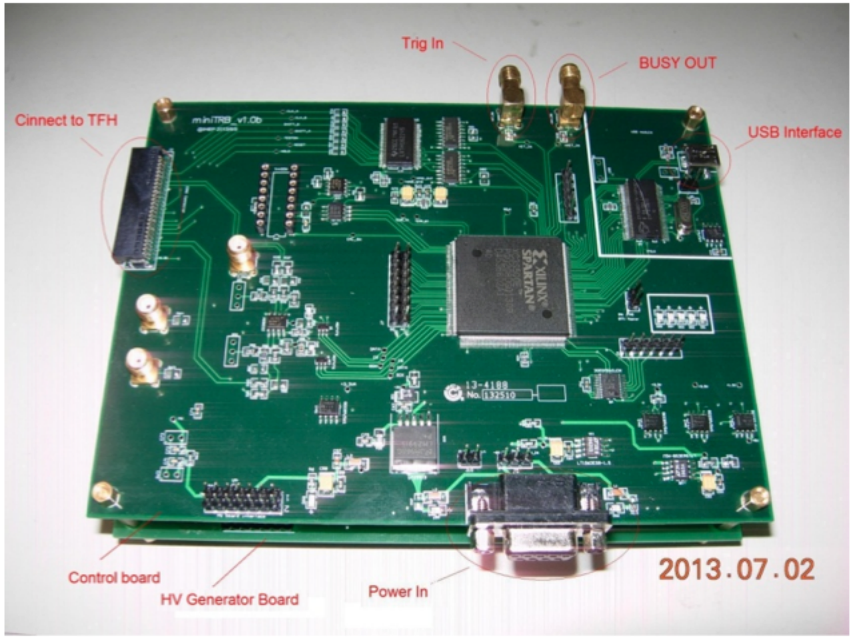


a total of
3072 VA chips

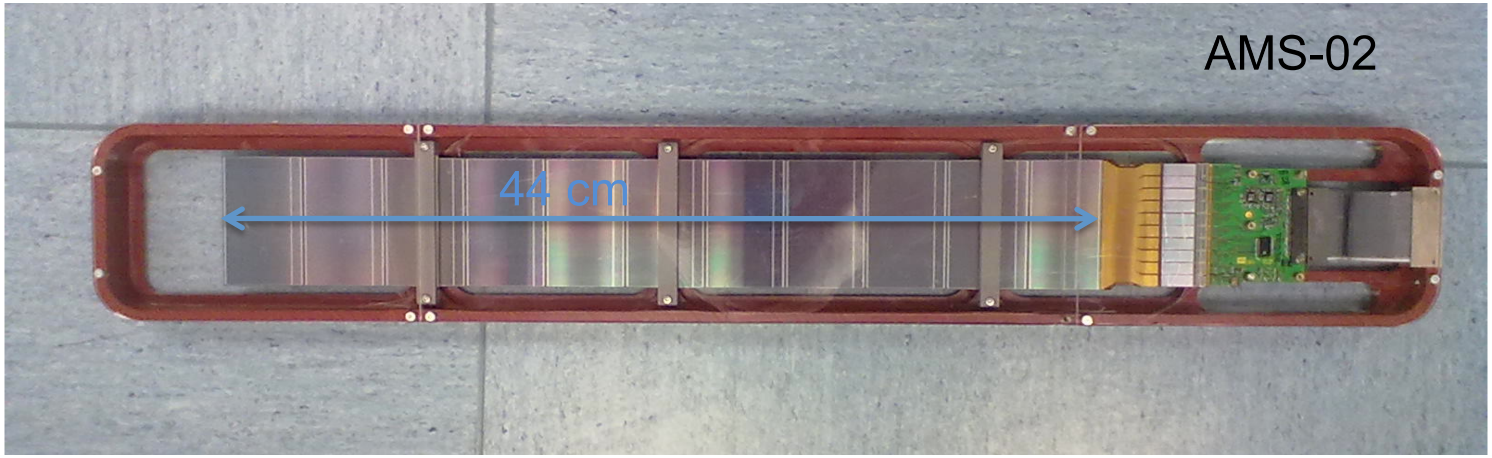
test are planned on the new chip to verify the behaviour

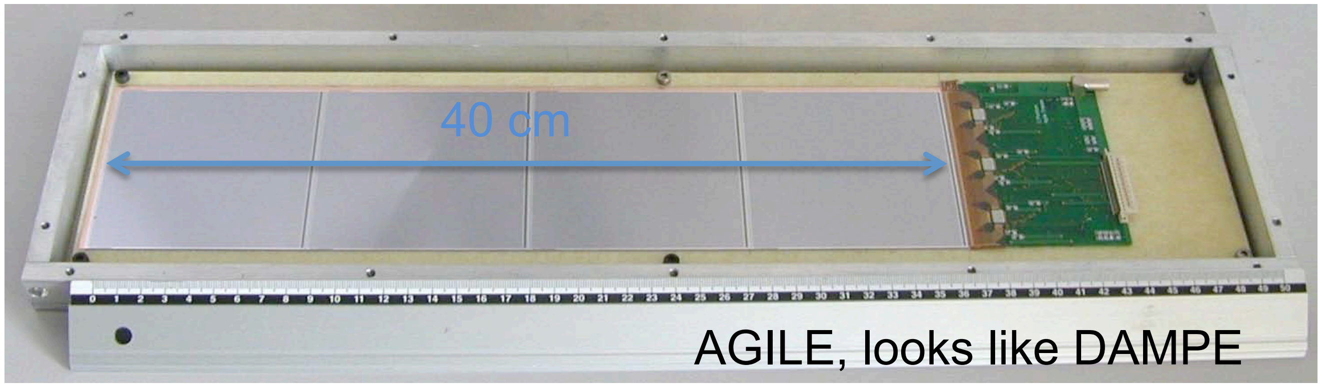
Readout FPGA based

- APA1000 (ProASIC family from ACTEL) will be used for flight to handle digitized data (74 kchannels, 12 bit ADC)
- total of 16 FPGA (compress data from 4608 channels each)
- currently we are developing a ground system:
  - implement and test calibration and data compression algorithms
  - readout ladders during assembly for QA

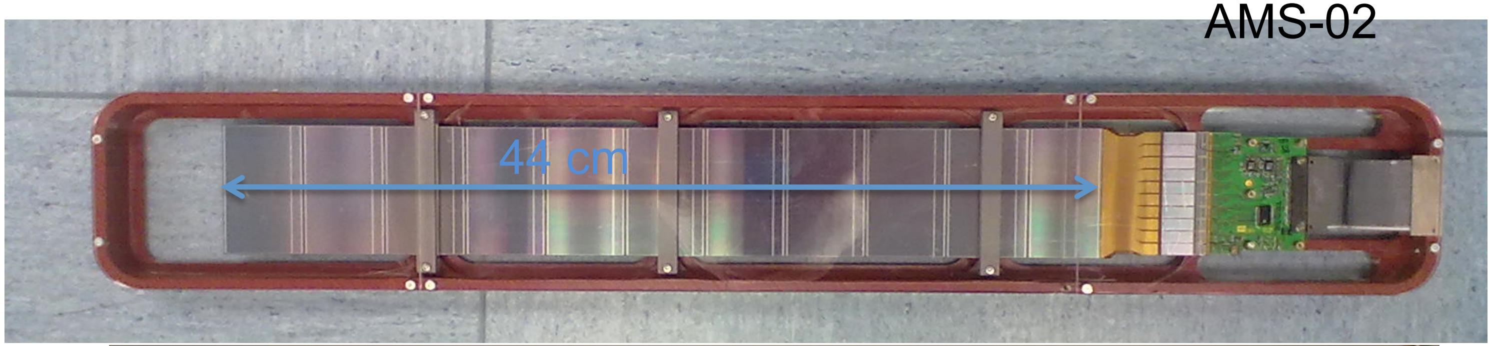


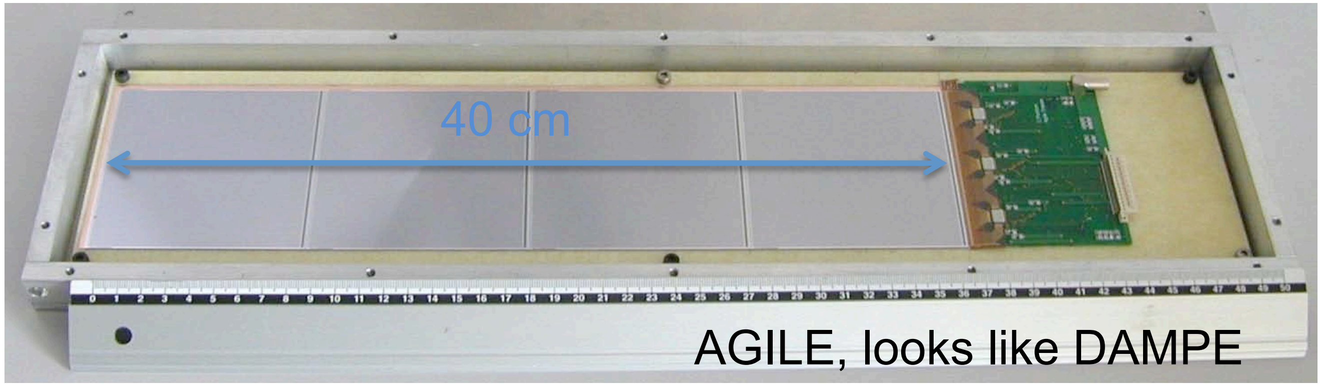
Silicon Ladders



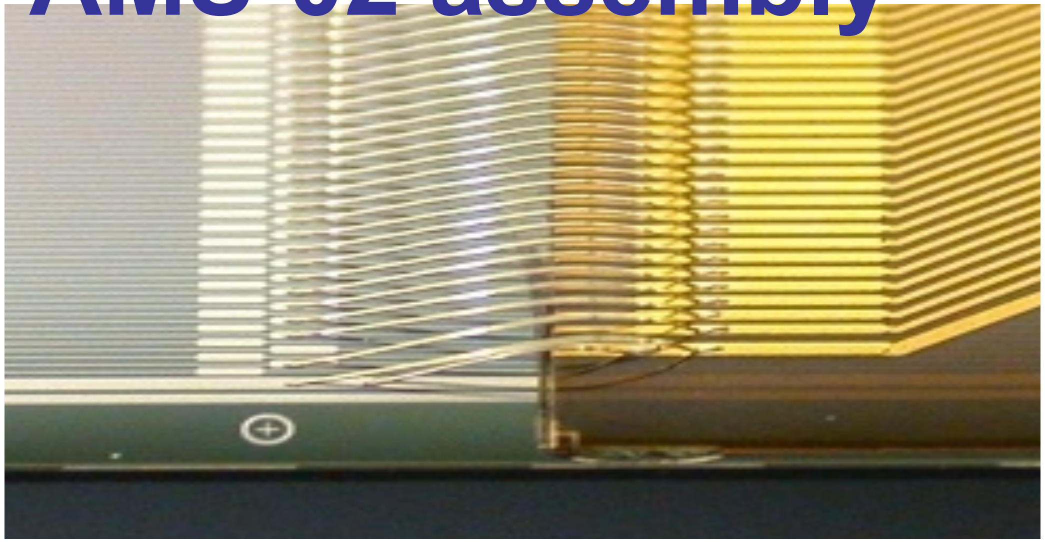


Silicon Ladders





AMS-02 assembly



Few numbers

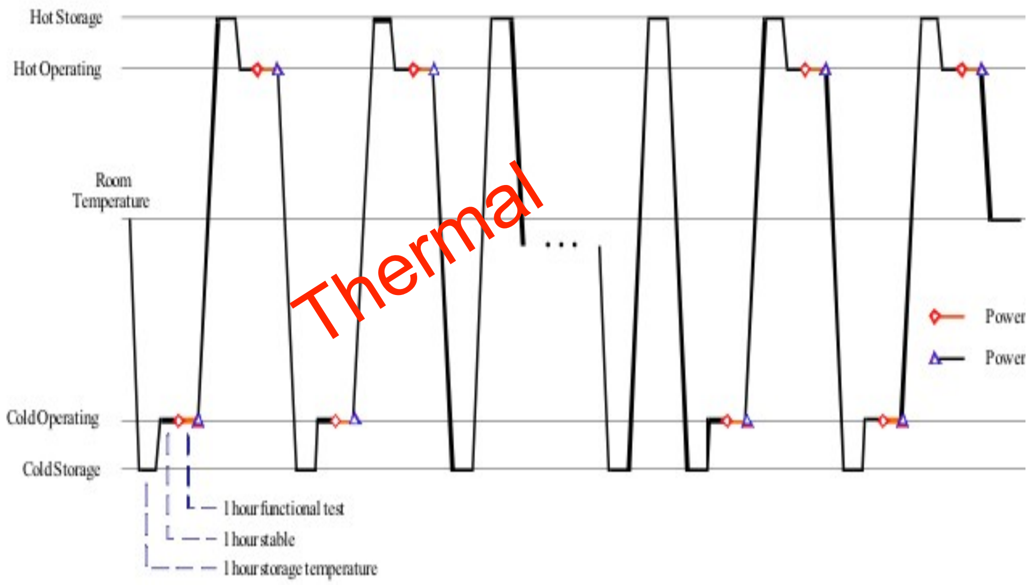
	AMS-02	DAMPE
# of layers	9, double sided	6+6 single sided
total Si surface	6.5 m^2, double sided	7 m^2, single sided
# of ladders	192	192
# of readout channels	~ 196 K	~ 74 K
# of wafers	2290	768
# of bonds per ladder	~ 17 k	~ 2 k

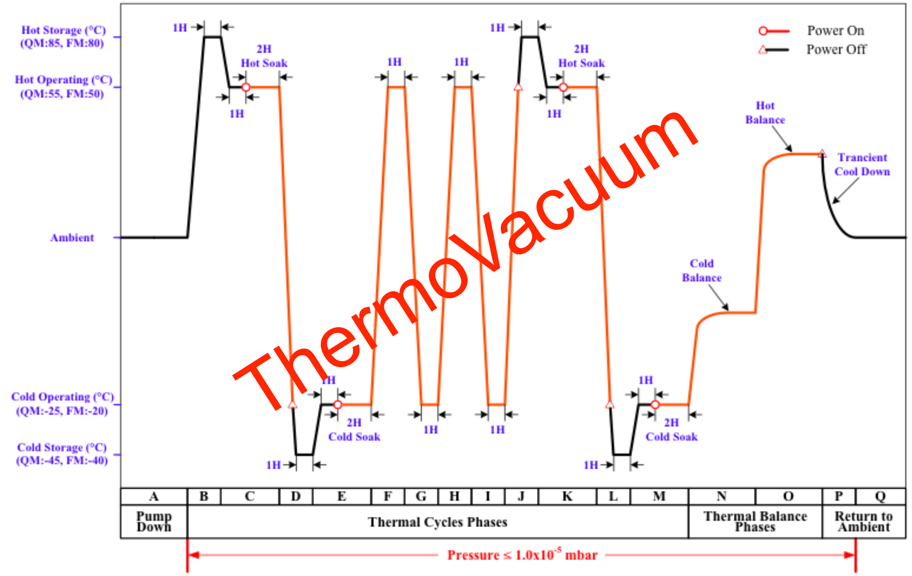
Qualification/Acceptance sequence

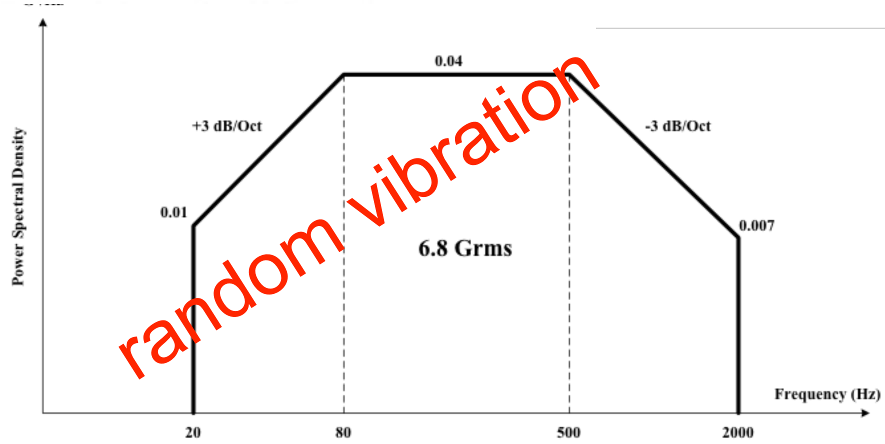
- Thermal test 10 cycles, functional test first and last two
- Vibration test, 3 axis, with functional test
- Thermal test 5 cycles, functional test first and last
- ThermoVacuum test, 4 cycles, functional test
- EMI/EMC test
  - Conducted emission and susceptibility
  - Radiated emission and susceptibility

- Temperature range:
  - +85°C/-45°C QM storage, +55°C/-25°C QM operational
  - +80°C/-40°C FM&FS storage, +50°C/-20°C FM&FS operational
- Vibration:
  - sine sweep, random vibration, sine sweep

Qualification/Acceptance sequence





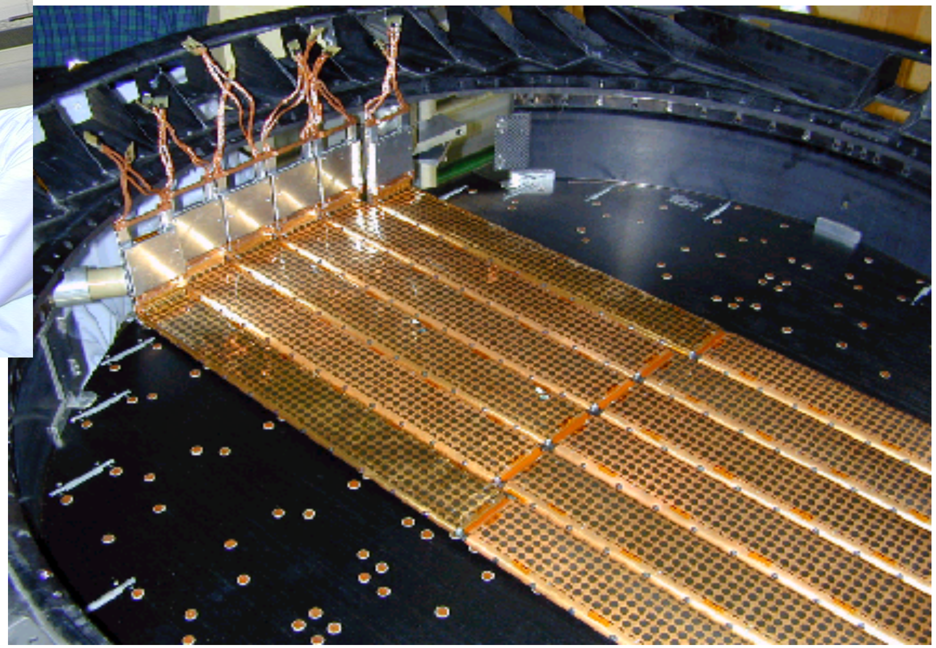


Notes: - 10 minutes for each X, Y and Z direction
- Functional test for each direction without failure

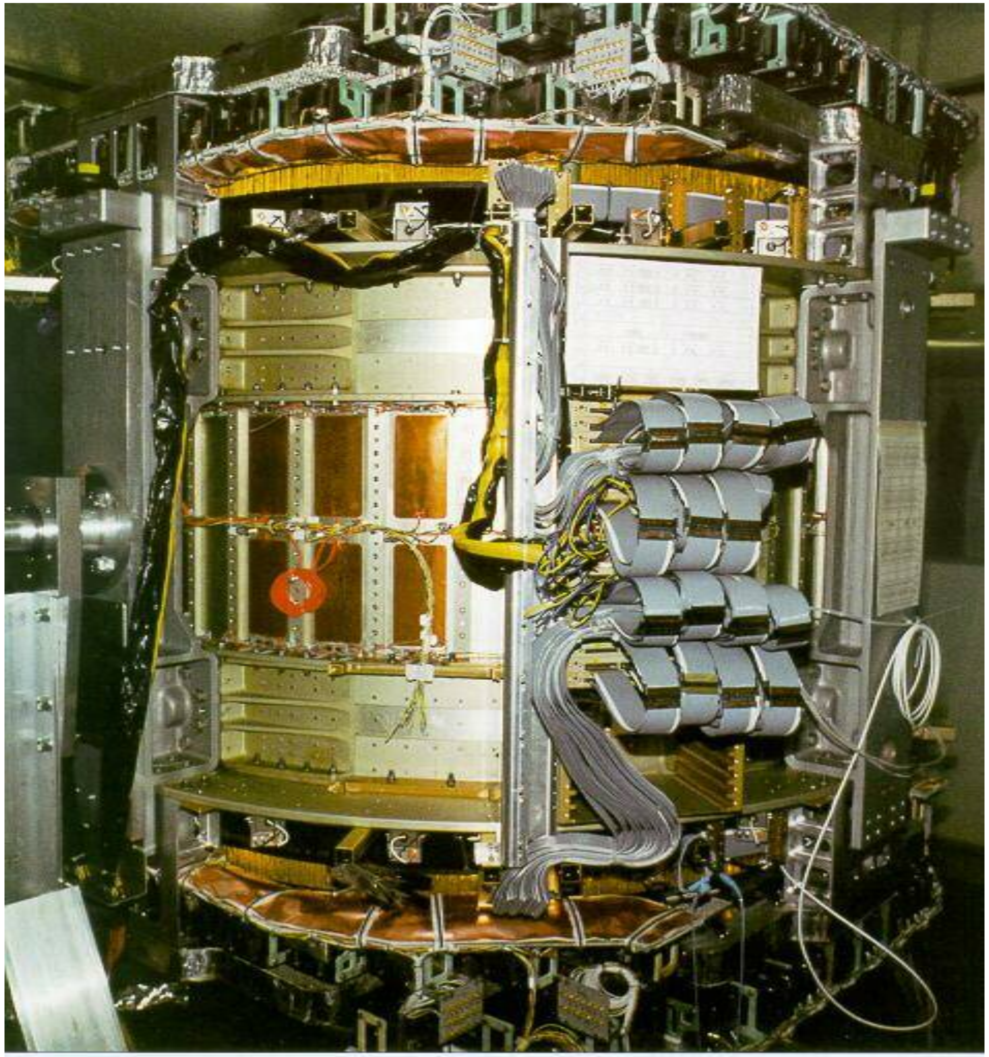
A new HEP project in space

- The DAMPE project is now running at full speed
- The silicon tracker design is frozen, based on the experience of previous space detector projects
- The challenge is to build and qualify the full tracker in two years
- Great physics potentials thanks to the extended energy range and improved detector resolution

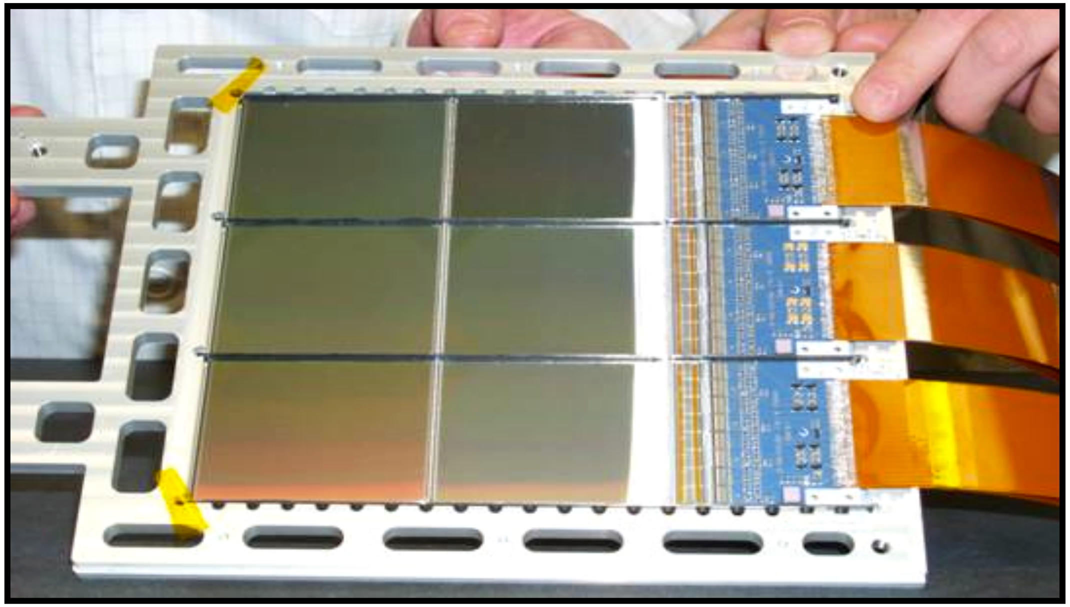
AMS-01 Silicon Tracker



AMS-01 1998

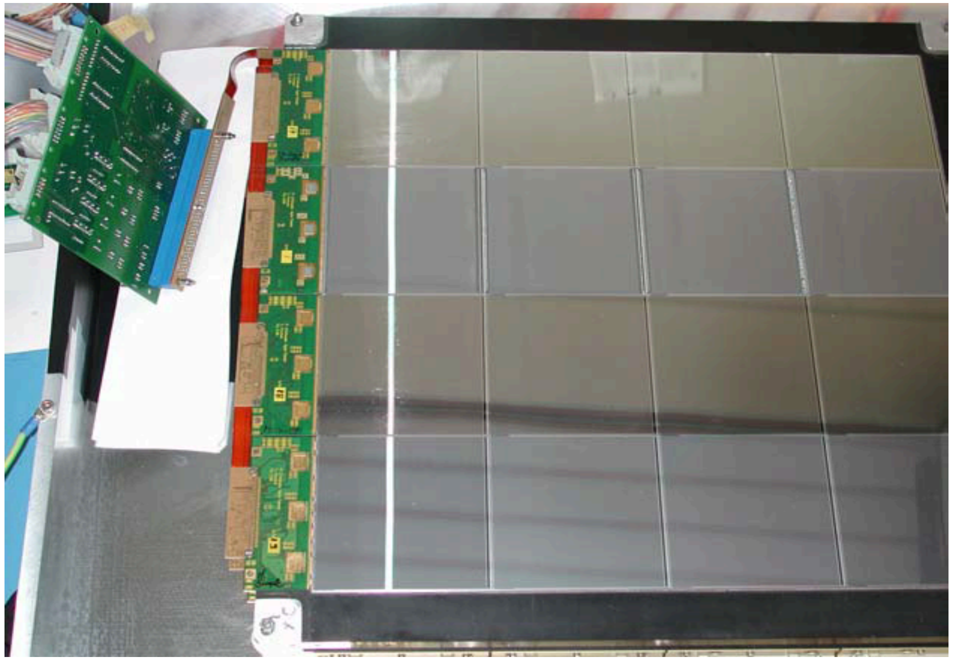


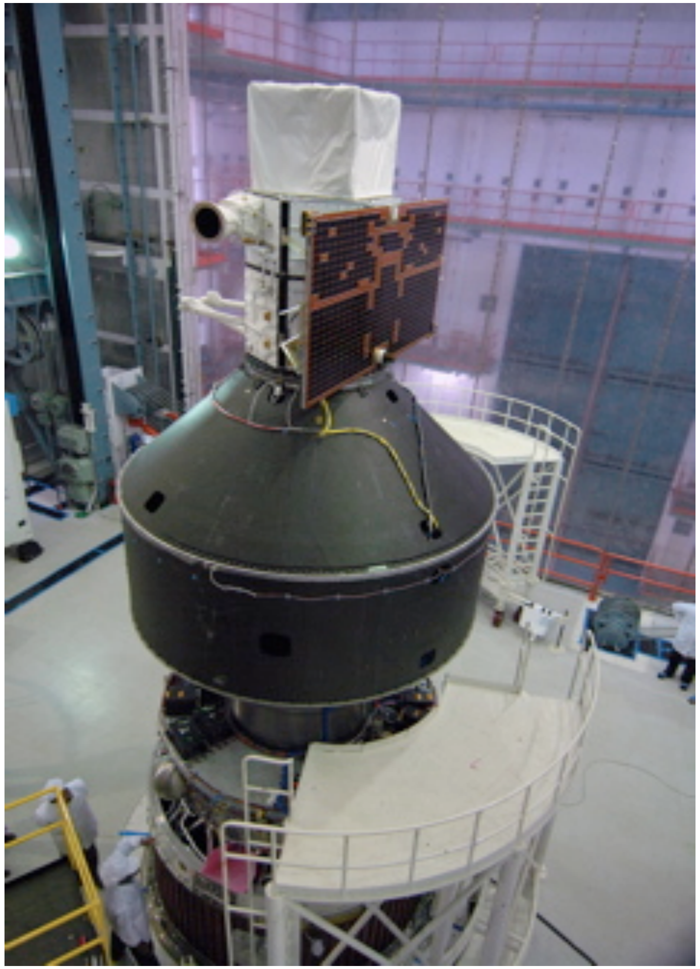
PAMELA 2006



Silicon detectors with electronics

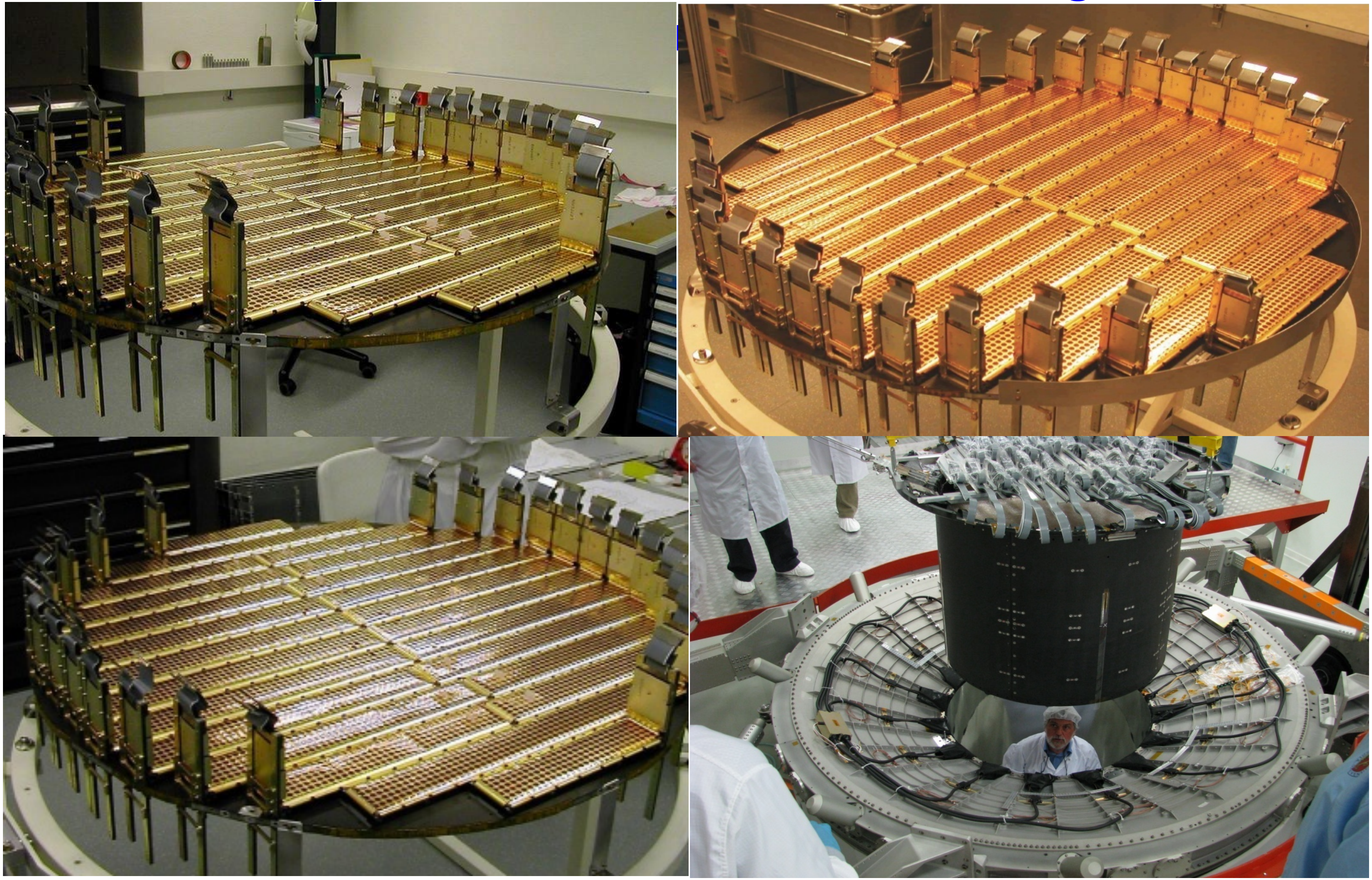
AGILE 2007





FERMI 2008

AMS-02: 9 planes with 200,000 channels aligned to 10



May 19, 2011: AMS installation completed.

http://dpnc.unige.ch/SVNDAMPE/DAMPE-Documents/SSD-characterization/Results/